Rainfall-Driven Diurnal Cycle of Ciliwung River: Overview and Future Prospect

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1. Introduction

Jakarta, the capital city of Indonesia, is now expanded as Great Jakarta or JABODETABEK (Jakarta, Bogor, Depok, Tangerang, and Bekasi) area. Jakarta is located in a lowland area at an average altitude of 2.4 m ASL (Fig. 1), and has rivers such as Ciliwung flown from mountainous areas in the southern side. This area has lost both lives and properties by flood events increasing recently, in 1996, 2002, 2007, 2008, 2010, 2011 and 2013. Among them floods in 1996, 2002, 2007 and 2013 occurred in very broad regions in the central city and made many damages.

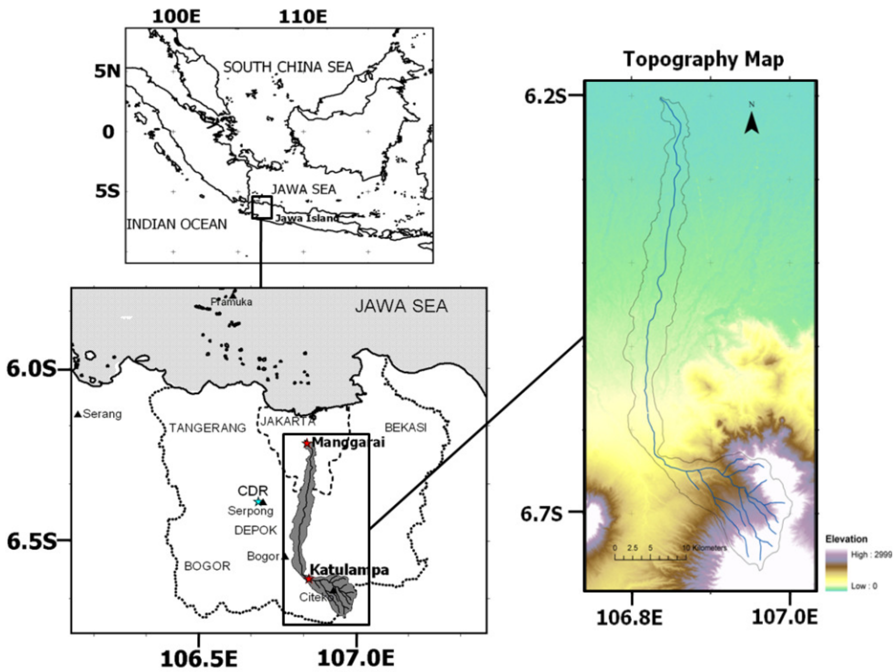

Figure 1. The topography map of Ciliwung River basin.

Our previous study (Sulistyowati et al., 2014) has found that the water level of Ciliwung River has persistent and systematic diurnal cycle pattern with an amplitude of 0.05 m caused probably by diurnal cycle of rainfall over Ciliwung River basin (6.2–6.8°S, 106.8–107.0°E). This diurnal cycle pattern observed there is free from the artificial water control as well as oceanic and global atmospheric tide. Figure 1 has shown that the Ciliwung River has narrow watersheds and steep slopes in its upstream to middle reaches (the length and catchment area are 97 km and 476 km^2, respectively), where runoff is very low because of the small recharge area, when extreme rainfall within even a short period in the upstream area usually leads to flooding downstream because rainwater in a narrow watershed flows into the river all at once (Tachikawa et al., 2004).

There are some studies on Jakarta flood using lumped and conceptual models (Farid et al., 2011; Santikayasa, 2006), and using a distributed hydrological (BTOPMC) model

(Hapsari et al., 2013). However, they were too limited to discuss the diurnal cycles of rainfall and water level. This paper introduces the first application of an advanced distributed hydrological (CDRMV3) model to the Ciliwung River basin. A simulation of diurnal cycle rainfall using CDRMV3 model for the first time during HARIMAU IOP2010 has been shown as well as the preliminary results and future prospect on Jakarta flood 2013.

2. Research method

2.1. Distributed hydrological model

The Cell Distributed Rainfall Runoff Model Version 3 (CDRMV3) is a distributed runoff model, which is suitable for un-gauged basin or poor information basins, because this model has ability to define model parameter values with spatially distributed data such as radar rainfall data, topographic data, land-use data, and remote sensing imagery (Kojima et al., 2003; Kojima et al., 2007; Hapsari et al., 2012).

The total discharge from a grid-cell per unit width q is calculated by summing the subsurface and surface flow and represented by the following single set of stage–discharge relationships (Tachikawa et al., 2004), as follows:

$$q = \begin{cases} v_m d_m \left(\frac{h}{d_m}\right)^{\beta}, & 0 \le h \le d_m \quad \text{(capillary subsurface flow)} \\ v_m d_m + v_a(h - d_m), & d_m < h \le d_a \quad \text{(non} - \text{capillary subsurface flow)} \\ v_m d_m + v_a(h - d_m) + \frac{\sqrt{i}}{n}(h - d_a)^m, & d_a < h \quad \text{(surface flow)} \end{cases}$$

where:

q : Discharge

v_a : Average velocity in the non-capillary pore

v_m : Average velocity in the capillary pore

d_a : Depth of non-capillary subsurface flow

d_m : Depth of capillary subsurface flow

h : Water depth

The governing equation of the model is for the flow rate of each grid-cell will calculate using the continuity equation, as follows:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r(t)\cos\theta$$

where:

x : Horizontal distance from upstream

t : Time

θ : Slope

r : Net rainfall intensity

The CDRMV3 model can describes the surface and subsurface flow using one-dimentional kinematic wave equations corresponding to stage-discharge relationship, the surface flow occurs if the water level is higher than total soil depth. This model has capability to simulate both short-term and continuous event and suited to estimate high flow of a single event in relatively short river (Kim et al., 2008; Apip et al., 2011).

2.2. Observation data

We have carried out intense observations mainly for meteorological parameters. Hydrological observations have been still limited, thus it is needed to use a numerical model for discussing the hydrological processes.

Radar rainfall data at 2-km CAPPI data has been used for model input and drainage paths have been produced based on the 1-km DEM (Digital Elevation Model) data from SRTM (Shuttle Radar Topography Mission) [http://dds.cr.usgs.gov/srtm/version2_1/ SRTM30/]. We used 15-min discharge data from Manggarai Station in the downstream of Ciliwung River for model validation.

The model needs the equivalent roughness of each land use category. The Ciliwung River basin is classified into nine land-use classes based on Ministry of Forestry, Indonesia, such as paddy, field, orchard, forest, wilds, urban, water body, swamp, and river.

3. Results and discussions

The water budget between a river and sea breeze may be considered approximately. If this balance could hold every day, the water vapour transported by sea breeze from ocean to land during day time should be equal to the evening rain in the mountain side, which might provide an increase of river water transport immediately. However, actually due to hydrological processes, the water cycle has a time lag and the water budget cannot be closed within a day.

The hydrograph at Manggarai station has been simulated by the CDRMV3 model using spatially distributed CDR rainfall observation data over the Ciliwung River basin. A result of simulation throughout the one month observation period (18 January – 15 February 2010) is shown in Fig. 2. The diurnal-cycle rainfall (involved in the CDR data) produces the diurnal cycle of water level, but the latter periodicity is not as clear as appeared in the observation. Another simulation during flood events for the last few days (13 – 15 February) has produced a better result as shown. This may be due to an effect of rainfall accumulation.

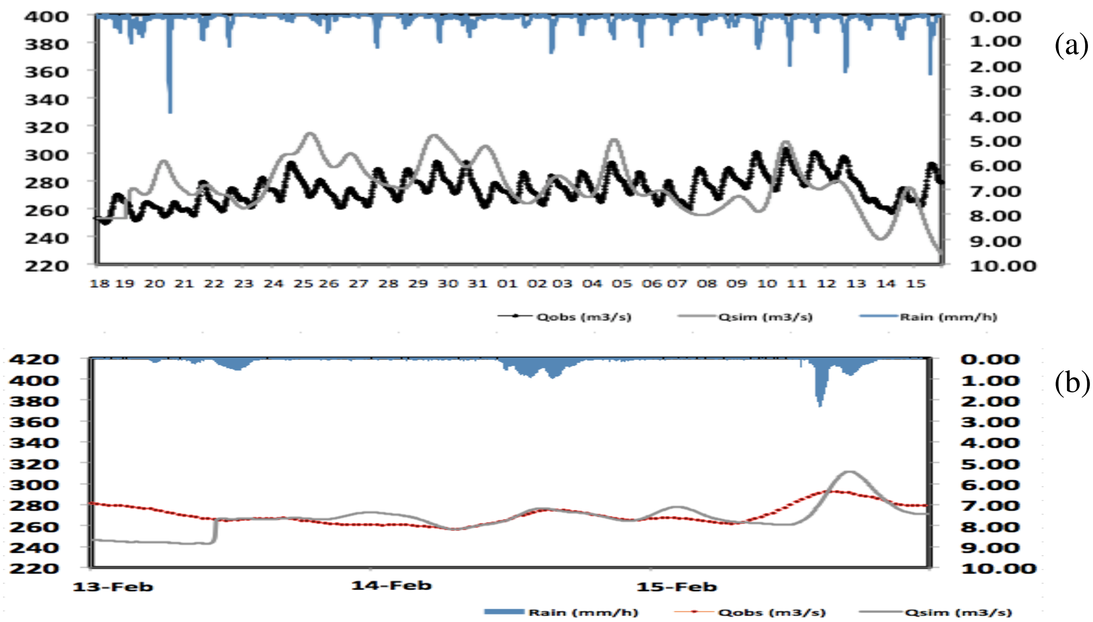

Figure 2. (a) Observed and simulated hydrographs on 18 January - 15 February 2010, and (b) the latter period of HARIMAU2010 IOP (13 - 15 February 2010).

The diurnal cycles of the water level in this study have response to the diurnal cycle rainfall described previously. The simulation results of Ciliwung River from the diurnal-cycle rainfalls may be dependent largely on hydrological parameters such as effective porosity, soil depth, roughness coefficient of river and urban, gravity water permeability and runoff rate.

We noted that the meridional migration of the rainfall area with the diurnal cycle was almost parallel to the flow direction of the Ciliwung River, which may provide massive amounts of water in a broader area of the river basin and cause an increased water level in the downstream on the following day. The Jakarta area is more hazardous to flooding when rainfall migrates continuously from the mountains to the coast (northward), as occurred during the flood in 2007 (Wu et al., 2007). During the current observational period, smaller but similar flood events occurred on 10 and 13 February.

4. Conclusion and future prospect

As mentioned in the previous section, when the rainfall area (cloud) migrates with a sea-land breeze circulation roughly parallel to the river flow, the total amount of diurnal rainfall over the river basin is increased, but the diurnal cycle of river water is not significantly changed. In the case of the serious floods of 2007 and 2013, water level data of the Ciliwung River indicated a rise of about 20 times (2 m) after the peaks of rainfall in the diurnal cycle reported here. Figure 3 shown a flood event in 2013 (~2.5 m at its maximum amplitude) occurred in a different phase of the diurnal-cycle of cloud migration (from sea to land in the morning), which interacted with the intraseasonal variation (Wu et al., 2013).

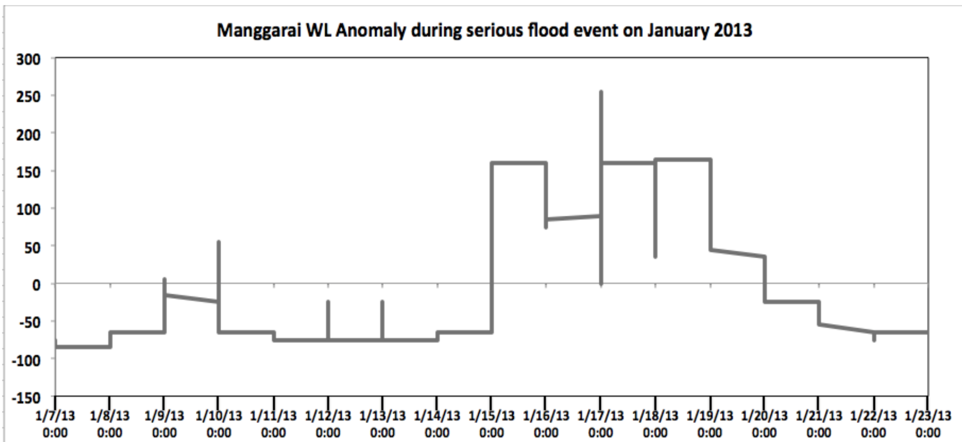

Figure 3. The water level anomaly during serious flood event on 2013 at Manggarai Station, water level increase about 2.5 at maximum amplitude.

Hapsari et al. (2013) mentioned that during flood event on 2013, the extreme rainfall occured about 5-days with the maximum daily was 140 mm/day (January 17) and hourly rainfall was 18 mm/hour (January 17 18:00 LT). At Manggarai, the increasing of water level occurred from January 15 (01:00 LT) to January 20 or about 5 days, peak discharge was 386.52 m^3/s (January 17 10:00 LT). But the detail characteristic of rainfall during 2013 has not been studied.

To understand the meteorological and hydrological characteristics of the flood event in 2013 is very important for the flood disaster mitigation. For the future study, analyzing the detail characteristic of the diurnal-cycle rainfall over Jakarta region and applying the distributed hydrological model (CDRMV3) for Ciliwung River basin should be done for flood monitoring and prediction.

The results of this study can be applied surely for many places over the Indonesian maritime continent. In Jakarta area, the National Disaster Prevention Agency (BNPB) is starting to use the real-time rainfall observations by the CDR. In future some hydrologic measurements will be applied in real time to a hydrological distributed model as studied here, and simulated results will be used for preventing/decreasing flood disasters. This part will be improved also by the knowledge on tropical hydrological processes such as the diurnal cycle of Cliwung River obtained in this study.

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